

# RESEARCH FUNDAMENTALS SERIES

Vapor Processing  
of Foods:  
*A Foundation Science*



## I N T R O D U C T I O N

This issue of the research Fundamental Series was taken from paper and lectures given by Mr. Leo Loeb, Foodservice Research Consultant for Winston Industries in Louisville, Kentucky. Mr. Loeb's research in food chemistry is critical to the development of equipment for the rapidly expanding technological needs of the foodservice industry.

In preparing this paper, Mr. Loeb made wide use of a large number of investigators from food processing and appropriate Industries. This paper and other activities by Mr. Loeb assists the company in developing equipment with improved food processing capabilities that require fewer human disciplines.

# Vapor Processing of Foods: *A Foundation Science*

## The Unique Technology of the CVap® Vapor Oven

The vapor oven concept, involving a dual temperature system with the water evaporator and oven air independently controlled at desired settings and providing a wide range of relative humidities within the oven cavity, is believed to be technically unique. Further, the implementation of this control concept in the CVap Vapor Oven and the DeliChef with microprocessor control which allows for sequentialized process at one or more preset conditions; e.g., COOK & BROWN, COOK & HOLD, COOK, BROWN & HOLD, PROOF & BAKE, is known to be unique among commercial offerings and in the pertinent patent literature.

The vapor oven with the dual temperature control concept can provide numerous useful functions in the foodservice industry. However, the two functions which are most unique in a technical sense are its ability to hold hot, cooked foods in the “as prepared” condition for extended time periods and its ability to cook meats and poultry to desired doneness levels with minimized yield loss during processing. Both of these functions will be discussed relative to the body of technical literature pertinent for the application.

### HOT FOOD HOLDING IN THE VAPOR OVEN

The capability of the vapor oven for holding hot, cooked foods for extended periods is based on the matching of the relative humidity of the oven environment to the equilibrium relative humidity or water activity of the food being held. With the food in equilibrium with the oven atmosphere little or no change in moisture content can occur relative to the “as prepared” state. The surface temperature of the food comes into equilibrium with the preset temperature of the evaporator and is held constant at any desired level. The air temperature of the oven is normal pre-set at a somewhat higher temperature. The differential between these two temperatures determines the relative humidity of the oven atmosphere. Depending on the magnitude of this differential, essentially the whole relative humidity range from 100% down can be obtained. With food temperature and moisture content held constant, texture and other aesthetic qualities can be maintained at fully acceptable and salable levels for a matter of hours.

In order to achieve the desired match between oven environment and food to be held, one must have knowledge of or be able to make an educated estimate of the water activity of the food in question. Fortunately, a

major theme in food science research for the past two decades. Numerous reference texts have been published on this subject; those we have consulted are as follows:

<sup>1</sup>*Water Activity and Food*, J.A. Troller and J.H.B. Christian, Academic Press, New York, 1978.

<sup>2</sup>*Water Activity: Theory and Applications to Food*, L.B. Rockland and L.R. Beuchat, Editors, Marcel Dekker, Inc., New York, 1987.

<sup>3</sup>*Moisture Sorption: Practical Aspects of Isotherm Measurements and Use*, T.P. Labuza, Am. Assoc. Of Cereal Chemists, St. Paul, 1984.

<sup>4</sup>*Water Relations of Foods*, R.B. Duckworth, Editor, Academic Press, New York, 1975.

From information in the technical literature combined with internal laboratory measurements, we have been able to specify the water activity for a wide variety of pertinent foods. Once the water activity or equilibrium relative humidity of the food is known, it is an easy matter to set the evaporator and air temperature of the oven to give the required matching humidity. These temperature settings are given for a wide variety of foods in the Use and Care Manuals of the various vapor ovens.

One might ask why the food scientists with their vast knowledge of the moisture properties of foods did not jump to the idea of the vapor oven with the environment matched to the food. Their interests were totally different; they were primarily interested in stabilizing foods for long-term shelf life in the absence of refrigeration. They focused on reducing the water activity of the food to the level where chemical stability would be assured and microbiological growth would be inhibited during long-term storage. For intermediate moisture foods intended for human consumption, this was achieved by dehydration followed by packaging in moisture impermeable films. For pet foods, e.g., Gainsburgers, the reduction of activity was obtained by the addition of water binding solutes such as salt or sugar.

The food scientists were thus interested in knowledge of water activity as a means for achieving long-term shelf stability in the range from months to years. Conversely, our interest was in holding cooked foods at a fixed serving temperature with the maintenance, textural and aesthetic properties for a matter of a few hours at most. The food scientists were mainly in the employ of food companies or engaged in university research sponsored by the large food companies; they were not in the equipment business and apparently did not see the implications of their work

on water activity as a key element in the development of an improved means for short-term holding of hot, cooked foods. Based on the examination of commercially available holding cabinets, it appears that equipment manufacturers do not understand or appreciate the value of controlling humidity during holding. Other manufacturers have made provisions for adding moisture via water pans located in their cabinets. However, these water pans have no temperature control and function as “slave units” drawing heat from the air heaters. While they recognize the value of added moisture, no effort has been made to control the relative humidity in relationship to the food being held.

### MEAT COOKERY IN THE VAPOR OVEN

The vapor oven, with its previously described humidity control system, performs excellently in the slow cooking of roasts and poultry, with extremely low yield losses. The technical literature pertaining to the cooking of meats has been surveyed to determine if any published studies anticipated the high benefits of humidity control.

At the outset it should be understood that the research on meat cookery is voluminous. Many of these studies at the academic/institutional level are characterized by empiricism, with emphasis on end-product evaluations. Very few of such studies have aimed at developing a unified model of the meat cooking process suitable for equipment design considerations.

Several standard texts are available which summarize the main themes of research on meat and meat cookery. These are of high value for anyone needing a standardized view of the state of the art. Some that can be recommended are:

<sup>1</sup>*Food Theory and Applications*, P.C. Paul and H.H. Palmer, Editors, John Wiley and Sons, New York, (1972).

<sup>2</sup>*The Science of Meat and Meat Products*, J.F. Price and B.S. Schweigert, Editors, Food and Nutrition Press, Westport, CT (1978).

<sup>3</sup>*Principles of Meat Science*, J.C. Forrest, et.al., W.H. Freeman & Co., New York, (1975).

Wherein humidity control is mentioned in most studies, it is largely an all-or-nothing matter. Many studies are concerned with roasting of meats in dry ovens or convection ovens where the only moisture available in the oven atmosphere is that evaporating from the meat load itself. Other studies, usually concerned with tenderizing of lower quality cuts high in connective tissue, have investigated cooking in sealed plastic bags at essentially 100% relative humidity.

Meat cooker research, in general, has not been much help in explaining the technical performance of the vapor oven. However, we have uncovered at least two research groups who studies the meat cooking process in terms of heat and mass transfer. Both these groups developed a broad conceptual understanding of the meat cooking process which serves as a scientific validation of the concepts implemented in the Winston vapor oven. It should be understood that the Winston vapor oven was invented, patented, and developed independently of these researches. Yet it is technically satisfying to know that similar conclusions have been obtained in basic studies by high quality research institutions. In this context, the following references are cited as of particular pertinence:

<sup>4</sup>*Cooking of Beef by Oven Roasting: A Study of Heat and Mass Transfer*, N.E. Bengtsson, et. Al., Journal of Food Science, Vol. 41, p. 1047. (1976).

<sup>5</sup>*Water Loss Rates and Temperature Profiles of Dry Cooked Bovine Muscle*, E.W. Godsalve, et.al., Journal of Food Science, Vol. 42, p. 1038, (1977).

<sup>6</sup>*Effect of Oven Conditions and Sample Treatment on Water Loss of Dry Cooked Bovine Muscle*, E.W. Godsalve, et. al., Journal of Food Science, Vol. 42, p. 1325, (1977).

<sup>7</sup>*Mechanisms of Water Loss of Bovine Muscle Dry Cooked From The Frozen State*, C.C. Hung, et. al., Journal of Food Science, Vol. 43, p. 1191 (1978).

The work of Nils Bengtsson and his colleagues at the Swedish Food Institute in Goteborg (Reference No. 4 above) is particularly pertinent in relation to the ideas incorporated in the Winston vapor oven. The following quotations from their paper will make this clear: “During cooking in an oven with convective heating, the meat surface remains wet during most of the heating cycle, which means that the primary stage of dehydration prevails and that weight loss by evaporation is directly proportional to heating time. The wetted surface will then remain close to the wet bulb temperature of the oven air space. For a given wetted surface temperature, the driving force for heat transfer to the interior will remain constant, irrespective of oven air temperature.” Bengtsson, et.al., go on to demonstrate that at higher meat surface temperatures the internal temperature gradient is steeper, the cooking time is shorter, and the weight loss is greater.

We have shown in numerous meat cook tests in the vapor oven that the meat surface temperature corresponds closely to the controlled temperature of the Evaporator which in turn corresponds to the wet bulb temperature of the oven environment. This constitutes a very powerful control means in that cooking time, and weight loss during cooking can be controlled by simply adjustment of the

temperature setting for the Evaporator. Slow cook, high yield results can be obtained with the Evaporator setting in the 179° to 180° range while faster cooking with somewhat greater losses can be obtained with the Evaporator setting advanced to the 190° to 200° range.

A second quotation from Bengtsson reemphasizes the importance of wet bulb temperature control during cooking. "It has been shown that during the primary stage of dehydration (cooking) heat transfer behaves as though the solid (meat) were heated in a water bath at the wet bulb temperature with a constant fluid-solid heat transfer coefficient."

In independent tests, we have shown that this second statement applies directly to the Winston vapor oven. In one test (Research Report 1988-24), a vapor oven was set for an Evaporator setting of 200° and an Air temperature of 200°, i.e., 100% relative humidity. The oven was preheated and allowed to fully stabilize at the set point conditions. In a first test, a load of large potatoes was cooked on a wire rack above the evaporator. The load required 58 minutes to reach an internal temperature of 200°. In a second test an equivalent potato load was cooked by immersion in the evaporator operating at 200°. The load required 57 minutes to reach a 200° internal temperature in the immersion run. This was interpreted to mean that the heating rate depends only on the surface temperature of the solid being cooked, and that this surface temperature was the same both during vapor phase heating at 100% relative humidity or during immersion in a water bath at the same wet bulb temperature.

One last quotation from Bengtsson makes clear the importance of wet bulb and relative humidity control on cooking time, yield and browning during meat cookery. "Our observations suggest means to reduce weight loss during evaporation and drippage. Since drippage becomes significant only above about 149°, it can be minimized by using heating conditions where this temperature is not exceeded. One possibility to do this is by using a very low, thermal driving force with correspondingly prolonged heating (cooking) time. Evaporative loss can easily be reduced by raising the relative humidity by lowering the oven air temperature to maintain the same thermal driving force." In one of their tests, the oven air temperature was dropped from 437° to 347° which increased the relative humidity from 2.4 to 7.2% and improved yield through reduction of evaporative loss.

Bengtsson, et. al., fully recognized the value of humidity management during meat cookery, but had relatively little

control in their single temperature, dry oven. In the vapor oven with its dual temperature control system, relative humidity management over the entire range can be easily exploited for maximized meat cookery. For example, for slow cook, high yield performance an evaporator setting of 170° and air setting of 180° can be utilized giving a relative humidity of about 79%. Roasts cooked in this manner will have a yield loss of about 10% at the rare doneness level. If faster cooking with browning is desired, settings of 190°/240° can be utilized giving a relative humidity of about 37%. Roasts cooked under this condition will cook much faster, will be beautifully browned, but will have somewhat higher weight loss in the 18 to 20% range. The Winston vapor oven thus appears as a full and independent implementation of technical concepts published by Bengtsson and his co-workers.

The other group that studied meat cookery in sufficient detail to generate a comprehensive model were at the University of Minnesota. This research was a joint effort of the Department of Chemical Engineering and the Department of Food Science and Nutrition. This unique combination of talents allowed for the interpretation of engineering heat and mass transfer data in terms of basic changes occurring in the meats and cereal produces being cooked.

In the first paper of their series (Reference No. 5 above) experimental data were presented on the water vapor emission rates and concurrent internal temperature for beef muscles heated in a dry oven. The vapor emission rate was continuously monitored from measurements of mass flow and relative humidity of the inlet and outlet air from the experimental oven. The moisture loss-rate data was shown to be constant with time over an extended period as the moisture content was being reduced from about 250% to 200%. During this constant rate-loss period, the meat surface is fully wetted, and first stage dehydration is occurring. It is during this constant rate period that both Winston and Bengtsson agree that the meat surface should be at the wet bulb temperature for an oven with convective heating.

According to Godsalve, et.al., the rise in moisture loss-rate period to the constant rate period is associated with the release of initially bound water by denaturation of the meat protein and the subsequent migration of this release moisture to the muscle surface. As the roasts are further heated, the critical temperature for collagen shrinkage is reached. Collagen is the connective fiber in meat and undergoes shrinkage in the 131° to 145° range. The collagen shrinkage provides the driving force that causes the released moisture to flow to the surface. This released moisture then essentially floods the surface, re-

establishes surface evaporation, and gives rise to the long constant loss-rate period during cooking. The constant rate-loss period ends when the roast interior can no longer provide sufficient moisture to wet the surface. The surface temperature then will rise above the wet bulb temperature and surface browning and other phenomena occur.

The workers at the University of Minnesota were not directly concerned with humidity as a means for controlling evaporative losses. However, their work does show that surface flooding of the meat surface occurs as the roast passes through the critical collagen shrinkage temperature and that the roast remains in the primary dehydration mode until the meat interior can no longer supply moisture to sustain a wetted film at the surface. The work of Hung, et.al., from the same group, also emphasizes the importance of the collagen shrinkage

temperature in controlling drippage losses. Taken together, the work of the Swedish group and the work at the University of Minnesota give a good insight as to the phenomena occurring during the cooking of meats. Also, their conclusions emphasize the technical correctness of the vapor oven dual temperature control concept, as well as the key importance of controlling both surface temperature and relative humidity for optimizing meat cookery.



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